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**BIBLIOGRAPHY ON THERMAL METALLIC
CONTACT CONDUCTANCE**

by **HARRY ATKINS**
Research Projects Laboratory

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ABSTRACT

This report is a revision of MSFC document R-RP-INT-64-8, dated February 14, 1964. It contains references in the area of contact heat transfer measurements and theories and contact surface parameter studies.

SUMMARY

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In the area of heat transfer in structures, the problems of heat transfer between the connected members is complicated by many complex parameters.

Since, especially in the exploration of space, a satellite's or spacecraft's survival is sometimes dependent on temperature control, it is not surprising that interest in thermal contact conductance has risen significantly in recent years. Presently, NASA funds five programs in this area, directly or indirectly. In all there are approximately twenty programs in this country and abroad. Because a thorough knowledge of past research is essential, an attempt has been made to collect all known references on this subject.

This report, a revision of MSFC document R-RP-INT-64-8, dated February 14, 1964, contains references in the area of contact heat transfer measurements and theories and contact surface parameter studies.

Author

I. CONTACT HEAT TRANSFER MEASUREMENTS AND THEORIES

Aaron, R. L., "A Theoretical Study of the Thermal Conductance of Joints With Varying Ambient Pressures," Southern Methodist University Masters Thesis, April 1963.

Aaron, R. L., Blum, H. A., "Heat Transfer Across Surfaces In Contact: Effects of Ambient Pressure Changes," A. I. C. H. E. Paper 63-B-9, May 1963.

Aaron, W. K. and Colombo, G., "Controlling Factors of Thermal Conductance Across Bolted Joints in a Vacuum," ASME Paper 63-W-196; see also Douglas Aircraft-Missile and Space Division Engineering Paper No. 1663.

Accomazzo, M. A., Miller, J., "Heat Transfer Across the Fuel-Clad Interface in Shrink Fit Hydride-Stainless Steel Fuel Elements," Nov. 8, 1963, North American Aviation Memo NAA-SR-MEMO-9184.

Adamantiades, A., "Experimental Determination of Contact Conductance for Some Stainless Steel Contacts," AEC Report No. NYO-9458, July 1962.

Alcock, J. F., "Communications on a Review of Recent Progress in Heat Transfer," Proc. Inst. Mech. Engrs., Vol. 149, pp. 126-132, 1943.

Alekseeva, O. P., Ivanov, A. V., "Heat Conduction Problem for an Unbounded Double-Layer Rod in the Case of Imperfect Contact Between the Layers," (Russian) IZV. VYS. UCHEB ZAV.; Energ. 3 No. 1:122-128, Jan. 1960.

Anderson, A. C., Salinger, G. L., Wheatley, J. C., "Transfer of Heat Below 0.15°K.," Review of Scientific Instruments, Vol. 32, No. 10, pp. 1110-1113, Oct. 1961.

Anderson, R. R., "Interface Thermal Conductance Tests of Riveted Joints in a Vacuum, "Douglas Aircraft Company (Tulsa Division) Report TU24871, February 6, 1964.

Andrews, I. D. C., "An Investigation of the Thermal Conductance of Bolted Joints, " Royal Aircraft Establishment (England), Technical Note WE.46, January 1964.

Armond, G., Lapujoulade, J., Paigne, J., "A Theoretical and Experimental Relationship Between the Leakage of Gases Through the Interface of Two Metals in Contact and Their Superficial Micro-Geometry, " Vacuum, Vol. 14, No. 2 pp. 53-57, Feb. 1964.

Ascoli, A. and Germagnoli, E., "Measurement of the Thermal Resistance of Uranium and Aluminum Flat Surfaces in Contact, " (Italian) Energia Nucleare, Vol. 3, No. 1, pp. 23-31, 1961, English Translation (USA), RSIC-99, Redstone Scientific Information Center.

Ascoli, A. and Germagnoli, E., "Consideration of the Thermal Contact Resistance Between Facing Flat Metal Surfaces, (Italian), Energia Nucleare, April 1956, Vol. 3, No. 2, pp. 113-118. English Translation (USA) DSIR-28790-ct.

Ashmead, F.A.H., "Thermal Resistance of Joints, " College of Aeronautics Diploma Thesis, Great Britain, May 1955.

Astakhov, O.P., Petrov, V.I., and Fedynskii, O.S., "Note on Contact Thermal Resistance in Heat Transfer to Liquid Metals, " Atom Energ. 11, No. 3:255-257, Sept. 1961. English Translation available(USA).

Atomic Energy Commission Report GA1939, "Thermal Conductivity of Reactor Materials, " Appendix A, "Problems in Obtaining Good Thermal Contact. "

Austin, J.B., "Relative Influence of Metallic Resistances in Thermal Circuits " p.82. The Flow of Heat in Metals, American Society for Metals, Oct. 1941.

Bailie, R. C., Fan, I. T., "Temperature Transient After Contact Heating, " Int. J. of Heat and Mass Transf., Vol. 6, No. 10, pp. 926-927, Oct. 1963.

Barber, A. D., Weiner, J. H., and Boley, B., "An Analysis of the Effect of Thermal Contact Resistance in a Sheet Stringer Structure. " J. Aeron. Sci., Vol., 24, No. 3, March 1957.

Barnes, L. J., Dillinger, J. R., "Thermal Boundary Resistance Between Some Superconducting and Normal Metals," Phys. Rev. Letters, Vol. 10, No. 7, pp. 287-289, April 1, 1963.

Barzelay, M. E., "Range of Interface Thermal Conductance for Aircraft Joints," NACA TN D-426, May 1960.

Barzelay, M. E., and Holloway, G. F., "The Effect of an Interface on the Transient Temperature Distribution in Composite Aircraft Joints," Syracuse University Research Institute Report No. 1620.290-1, March 1955.

Barzelay, M. E., and Holloway, G. F., "Effect of an Interface on Transient Temperature Distribution in Composite Aircraft Joints," NACA TN-3824, April 1957.

Barzelay, M. E., and Holloway, G. F., "Interface Conductances of Twenty-Seven Riveted Aircraft Joints," NACA TN-3991, July 1957.

Barzelay, M. E., and Schaefer, John W., "Temperature Profiles and Interface Thermal Conductance of Stainless Steel and Titanium Alloy Panels under Combined Loading and Heating." Syracuse University Report ME 406-577F, July 15, 1957.

Barzelay, M. E., Tong, K. N., and Holloway, G. F., "Thermal Conductance of Contacts in Aircraft Joints," NACA TN-3167, March 1954.

Barzelay, M. E., Tong, K. N., and Holloway, G. F., "Effect of Pressure on Thermal Conductance of Contact Joints," NACA TN-3295, May 1955.

Behrman, L. A., "Thermal Conductance of Two Stacked Composite Circular Cylinders with Mixed Boundary Conditions," ASME Paper 63-WA-147, November, 1963.

Berman, R., "Some Experiments on Thermal Contact at Low Temperatures," J. Appl. Phys. Vol. 27, No. 4, pp. 318-323, April 1956.

Berman, R., Mate, C. F., "Thermal Contact at Low Temperatures," Nature, Vol. 182, pp. 1661-1663, December 13, 1958.

Bernard, J. J., "La Resistance Thermique Des Joints," (French) Groupe Consultatif Pour La Recherche et la Realisation Aeronautiques, AGARD Report No. 212, October 1958. DDC File Copy AD221-409.

Bloom, Mitchell, F., "A Review of the Parameters Influencing Thermal Control Conductance Between Metal Interfaces," Douglas Aircraft Report SM-42082, August 9, 1962.

Bloom, Mitchell F., "Preliminary Results From a New Thermal Control Conductance Apparatus," Douglas Aircraft Engineering Paper 1672, August 1963.

Bloom, M. F., "Thermal Contact Conductance in a Vacuum Environment," Douglas Aircraft Report SM 47700, December, 1964. Presented at Fourth Conference on Thermal Conductivity, U. S. Radiological Defense Lab. San Francisco, California, October 13-16, 1964.

Blum, H. A. "Heat Transfer Across Surfaces in Contact; Transient Effects of Ambient Temperatures and Pressures," Progress Report - NASA Contract NSG 711. Also presented at 1964 Thermal Conductivity Conference, U. S. Naval Radiological Lab., San Francisco, California, Oct. 13-16, 1964.

Boeschoten, F., "On the Possibility to Improve the Heat Transfer of Uranium and Aluminum Surfaces in Contact," Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 9, p. 208-209, Geneva, August 1955.

Boeschoten and Van der Held, E., "The Thermal Conductance of Contacts Between Aluminum and Other Metals," Physics, Vol. 23, pp. 37-44, 1957.

Brooks, Jr., W. A., Griffith, G. E., and Strass, H. K., "Two Factors Influencing Temperature Distributions and Thermal Stresses In Structures," NACA Technical Note. 4052.

Brown, M.H.S. (Translator), "Thermal Conductance of Steel Joints," (Conductance Thermique Des Liaisons Acier) Sud Aviation Report C.R. 72.013-50, March 1960. English Translation from Royal Aircraft Establishment, Farnborough, England, Library Translation No. 950. (USA -DDC cy. # AD262-820, July 1961).

Browning, J. W., "A Transient Study of Thermal Contact Resistance," A study performed at Southern Methodist University, Dallas, Texas, May 12, 1962.

Brunot, A. W. and Buckland, F. F., "Thermal Contact Resistance of Laminated and Machined Joints," Trans. ASME, Vol. 71, pp. 253-257, 1949.

Brutto, E., Casagrande, I., and Perona, G., "Thermal Contact Resistance Between Cylindrical Metallic Surfaces," Energia Nucleare (Milan), Vol. 6, No. 8, pp. 532-540, August 1959.

Businger, J. A., Buettner, K. J. K., "Thermal Contact Coefficients," J. Meteorol., Vol. 18, No. 3, June 1961.

Butler, S., "The Effect of Joints on the Thermal Stress in Supersonic Flight," British Aircraft Ltd. Report T.O.R. 149, February 1962.

Campbell, W. E., "Use of Statistical Control in Corrosion and Contact Resistance Studies," Trans. Electrochem. Soc., Vol. 81, 1942.

Cetinkale, T. N., "Thermal Conductance of Metal Surfaces in Contact," PH. D. Thesis, London University, London, England, 1951.

Cetinkale, T. N., and Fishenden, M., "Thermal Conductance of Metal Surfaces in Contact," General Discussion on Heat Transfer, Conference of Inst. of Mech. Engr. and ASME, London, England, Sept. 1951.

Challis, L. J., Cheeke, J. D. N., "The Thermal Conductance of Copper-Lead-Copper Sandwiches at Liquid Helium Temperatures," Physics Letters, Vol. 5, No. 5, pp. 305-307, August 1, 1963.

Clausing, A. M., and Chao, B. T., "Thermal Contact Resistance in a Vacuum Environment," University of Illinois Experimental Station Report, ME-TN-242-1, August 1963. (See also ASME Paper 64-HT-16.)

Cole, R. L., "An Experimental Investigation of the Heat Transfer Mechanism Across an Aircraft Structure Joint," Master's Thesis, Southern Methodist University, Dallas, Texas, January 1961.

Cordier, H., and Maimi, R., "Experimental Study of the Influence of Pressures on Thermal Contact Resistance," French-English Translation (USA), SLA 63-10777 Acad. Des Sciences, Compts Rendus 250:2853-2855, April 25, 1960.

Cordier, H., "Experimental Studies of the Influence of Pressure on Thermal Contact Resistance," Annales de Physique, No. 1-2, pp. 5-19, 1961, Redstone Scientific Information Center, Redstone Arsenal, Alabama. Translation (USA) RSIC-116.

Coulbert, C. D., Liu, C., "Thermal Resistance of Aircraft Structure Joints," WADC Technical Note 53-50, June 1953.

Cunnington, G. R., "Thermal Conductance of Filled Aluminum and Magnesium Joints in a Vacuum Environment," ASME Paper 64-WA/HT-40.

Davis, W., "Thermal Transients In Graphite Copper Contacts," Brit. J. Appl. Phys., Vol. 10, No. 12, pp. 516-522, Dec. 1959.

Dean, R. A., "Thermal Contact Conductance Between UO_2 and Zircaloy 2," AEC Report CVNA-127, 1962.

Douglas Aircraft Company, Inc., "Thermal Resistance of Bolted Aluminum Joints," Technical Memorandum AZ-860-S/MECH-63-TM-50, January 28, 1963.

Dubovis, M. I., "The Evaluation of Temperature on the Plane of Contact in Systems with Heat Removal into a Semi-Infinite Medium," Soviet J. of Eng. Phys., INZH. F. Z. ZH. 4 No. 11, pp. 89-93, November 1961.

Dugeon, E. H., Prior, B. W. "The Contact Thermal Conductance of Aluminum-Sheathed Tubes," National Research Council of Canada Report MT-24, October 1954.

Dugeon, E. H., and Prior, B. W., "The Contact Thermal Conductance of an Aluminum-Sheathed Nickel or Tin-Plated Uranium Rod," National Research Council of Canada, Report MT-29, Sept. 26, 1955.

Dyban, E. P., Kondak, N. M., Shvets, I. T., "Investigation of Contact Heat Exchange Between Machine Parts," (Russian) IZV. AKAD. NAUK. SSSR OTD. TEKH. Vol. 9, pp. 63-69, Sept. 1954. English Translation (Great Britain) NO. IGRL-T/W.12, issued by United Kingdom Atomic Energy Authority Research and Development Branch Windscale Works. Translated by V.H. Brix, Capehurst Works.

Dyban, E. P., Shvets, I. T., "Contact Heat Transfer Between Two Flat Metallic Surfaces," (Russian) INZHERNO FIZICHESKII ZHURNAL, Vol. 7, No. 3, pp. 3-9, March 1964. English Translation (entire journal translated monthly) by Faraday Translations, N. Y.

Dyban, E. P., Kondak, N. M., Shvets, I. T., "Studies on Contact Heat Exchange Between Heat Engine Parts," (Russian) Trudy Institute Teploenergetina, No. 12, pp. 21-53, 1955, English Translation (USA), RSIC-322, Redstone Scientific Information Center, Redstone Arsenal Alabama.

Dyban, E. P., Shvets, I. T., "Air Cooling of Gas Turbine Motors," Chapter 10, "Contact Heat Exchange in Turbine Parts," pp. 191-233, IZDATEI 'STVO KIEVSKOGO UNIVERSITETA KIEV, 1959, English Translation-Technical Documents Liaison Office. MCL-1406/1+2+3+4 July 18, 1962. DDC Copy No. AD-281-848.

Dyban, E. P., and Kondak, N. M., "Research on Heat Exchange in Course of Contact Between Parts," IZV. AN SSSR OTD. TEKH. NAUK pp. 62-79, 1955(9). English Translation ASLIB-GB158.

Elliott, D. H., "Thermal Resistance Across Bolted Aluminum Joints and Across Flat Surfaces Pressed Together in a Vacuum," Douglas Aircraft Company, Inc. Technical Memorandum No. 89, Serial No. A3-863-K411-63, April 1964.

Elliott, D. H., "A Study of Thermal Resistance Across Aluminum Joints in a High Vacuum," "Model No. Saturn S-IVB," Douglas Aircraft Company Report SM-46759, December, 1964.

Fenech, H. and Rohsenow, W. M., "Thermal Conductance of Metallic Surfaces in Contact," U. S. AEC Report NYO-2136, May 1959.

Fenech, H., and Rohsenow, W. M., "Prediction of Thermal Conductance of Metallic Surfaces in Contact," J. Heat Transf., Vol. 85, pp. 15-24, Feb. 1963.

Fenech, H., and Henry, J. J., "An Analysis of Thermal Contact Resistance," Trans. Amer. Nucl. Soc., Vol. 5, No. 2, pp. 476-477, November 1962.

Fenech, H., "The Thermal Conductance of Metallic Surface in Contact," PH. D. Thesis, M.I.T., May 1959.

Fishenden, M., and Kepinsky, A., "Resistance to Heat Transfer in Gap Between Two Parallel Surfaces in Contact," Proceedings of the Seventh Congress on Applied Mechanics, Vol. 3, pp. 193-195, 1948.

Fisher, J. T., "The Design and Construction of an Apparatus to Determine the Heat Transfer Coefficient of 304 Stainless Steel Joints in Contact in a Vacuum," M.S. Thesis, Dept. of Chemical Engineering, University of Rochester, Rochester, New York, 1964.

Francis, R. K., Tinklepaugh, J. R., "Thermal Conductivity in Ceramic-Metal Laminates," J. Amer. Ceram. Soc., Vol. 43, No. 11, pp. 560-563, November 1960.

Fried, E., and Costello, F. A., "Interface Thermal Contact Resistance Problem in Space Vehicles," American Rocket Society Conference, Palm Springs, California, April 1961 (See also ARS Journal, Vol. 32, pp. 237-243, 1962).

Fried, E., "The Thermal Conductance of Space Vehicle Interfaces-Experimental Results," General Electric Report No. 61GL65, March 1961.

Fried, E., "Thermal Joint Conductance in a Vacuum," ASME Paper No. AHGT-18, Aviation and Space Hydraulic and Gas Turbine Conference, Los Angeles, California, March 1963.

Fried, E., "Study of Thermal Contact Conductance," Final Report NASA (M-RP-T) Contract NAS8-5207. General Electric Document No. 6450652, May 1, 1964. See also International Thermal Conductivity Conference - National Physical Laboratory - Teddington, Middlesex England, July 15-17, 1964.

Fried, E., "Metallic Interface Thermal Conductance - Measurement Techniques," Paper presented at the Fourth Conference on Thermal Conductivity, U.S. Naval Radiological Defense Laboratory, San Francisco, California, Oct. 13-16, 1964.

Fried, E., "Study of Interface Thermal Contact Conductance," Final Report NASA (M-RP-T) Contract NAS8-11247, April 1965.

Gardner, K. A., and Carnavos, T. C., "Thermal Contact Resistance in Finned Tubing," J. Heat Transf., C82 No. 4, 1960.

Gatewood, B. E., "Effect of Thermal Resistance of Joints Upon Thermal Stresses," Air Force Institute of Technology Report 56-6, May 1956, DDC No. AD106-014.

Gex, R. C., "Thermal Resistance of Metal-To-Metal Contacts," An Annotated Bibliography, Lockheed Special Bibliography Report SB-61-39, July 1961.

Gilchrist, E. J., "Experimental Interface Heat Transfer Contact Coefficients in the Minuteman Solid Rocket Nozzle," Aerophysics Dept. Solid Rocket Operations, Aerojet General Corporation (Sacramento, Cal.) Report, July 1964. Air Force Contract AF04(694) - 258.

Graff, W. J., "Thermal Conductance Across Metal Joints," Machine Design, Vol. 32, pp. 166-172, 1960.

Griffith, G. E., and Miltonberger, G. H., "Some Effects of Joint Conductivity on the Temperatures and Thermal Stresses in Aerodynamically Heated Skin Stiffener Combinations," NACA Technical Note 3699, (1956).

Hain, P. L., "Thermal Conductance of an Interface," Southern Methodist University, Master's Thesis, Dallas, Texas, May 26, 1961.

Ham, A. C., "The Thermal Resistance of Dry Metal Surfaces in Contact," (Unpublished Work) The Royal Aircraft Establishment, London, England, 1955.

Hefley, H. F., "Thermal Conductance of Interfaces," Southern Methodist University, Master's Thesis, Dallas, Texas, September 1962.

Held, W., "Heat Transfer Between Worked Metal Surfaces," (German) Allgemine Warmetechnik, Vol. 8, No. 1, pp. 1-8, 1957, English Translation (USA) RSIC-76, Redstone Scientific Information Center, Redstone Arsenal, Ala.

Henry, J. J., and Fenech, H., "The Use of Analogue Computers for Determining Surface Parameters Required for Prediction of Thermal Contact Conductance," ASME Paper 63-WA-104, 1963; also, see J. of Heat Transf., Transaction of ASME, Vol. 86, Series C, No. 4, pp. 543-552, November 1964.

Henry, J. J., "The Thermal Resistance of Metals in Contact," M. S. Thesis, M.I. T., August 1961.

Henry, J. J., "Some Methods of Surface Analysis for the Prediction of Thermal Resistance of Metal Contacts," AEC Report NYO 9457, Nov. 1961.

Henry, J. J., "Thermal Conductance of Metallic Surfaces in Contact," AEC Report NYO-9459, Feb. 1963.

Holloway, G. F., "The Effect on an Interface on the Transient Distribution in Composite Aircraft Joints," Syracuse University Thesis, 1954.

Holm, R., "Thermal Conduction Through Nominally Flat Metallic Contacts in a Vacuum Environment," To be published.

Holm, R., "Calculation of the Temperature in a Contact Heated in the Contact Surface and Application to the Problem of Temperature Rise in a Sliding Contact," J. Appl. Phys., Vol. 19, pp. 361-366, 1948.

Holm, R., Electrical Contacts Handbook, Springer Verlag, Berlin, 3rd Ed., 1958.

Horn, S. S., "Thermal Contact Resistance of Graphite," M. S. Thesis, M. I. T.

Horvey, G., Edsall, R. H., "The Interface Temperature of Two Media in Poor Thermal Contact," ASME Metallurgical Society Transaction, Vol. 218, No. 5, pp. 927-933, November 1960.

Houtman, W., "Selection and Evaluation of Interstitial Materials for Use Between Cold Plates and Equipment in a Vacuum Environment," McDonnell Aircraft Corporation Report TR052-068.02.04, April 1963, DDC No. AD418-941.

Ingersall, Zobel, Ingersall, "Heat Conduction," Section 3.13, "Contact Resistance," McGraw-Hill Book Co., 1948.

Ittner, W. B., Magill, P. J., "A Survey of Contact Resistance Theory for Nominally Clean Surfaces," IBM Journal, January 1957.

Jacobs, R. B., and Starr, C., "Thermal Conductance of Metallic Contacts," Rev. Sci. Instr. Vol. 10, pp. 140-141, 1939.

Janson, R. M., "The Heat Transfer Properties of Structural Elements for Space Instruments," M.I.T. Instrumentation Lab Report E-1173, June 1962.

Jelinek, D., "Heat Transfer of Proposed Structural Joints in the Rocket Package for the F-86D Airplane," North American Aviation Lab Report No. NA-49-831, Sept. 30, 1949.

Kapinos, V. M., and Il'chenko, O. T., "Determining the Contact Thermal Resistance of Mixed Pairs," KHARKOV. POLITEKHNICHESKII INST. TRUDY. SERIYA METALLURGICHESKAIA, Vol. 5, pp. 217-223, 1959.

Kapinos, V. M., and Il'chenko, O. T., "Thermal Resistance of a Contact Layer," KHARKOV. POLITEKHNICHESKII INST. TRUDY. SERIYA METALLURGICHESKAIA, Vol. 5, pp. 160-181, 1959.

Kapinos, V. V., Il'chenko, O. T., "Thermal Conductivities Due to Protuding Asperities," (Russian) IZVESTIYA VYSSHIKH UCHEBNIYAK ZAVEDENII ENERGETIKA, No. 9, pp. 77-89, 1958 English Translation (USA) RSIC-281. Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Kapinos, V. M., Il'chenko, O. T., "Thermal Resistance of Turbine Blade Base Joints," (Russian) ENERGMASHINOSTROENIE, Vol. 5, No. 6, pp. 23-26, June 1959, English Translation (USA) RSIC-261. Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Karush, W., "Temperature of Two Metals in Contact," AEC Report AECD-2967, Dec. 22, 1944.

Kaspareck, W., Dailey, R., "Measurement of Thermal Contact Conductance in a Vacuum," ASME Paper No. 64-HT-38, August 1964.

Keller, J. D., "Heat Transmission in Strip Coil Annealing," Iron and Steel Engineers, p. 60, November 1949.

Kouwenhoven, W. B., Tampico, J., "Measurement of Contact Resistance," paper presented at the Annual Meeting of the American Welding Society, Cleveland, Ohio, October 21-25, 1940.

Kouwenhoven, W. B., Tampico, J., "Surface Polish and Contact Resistance," The Welding Journal Research Supplement, Vol. VI, 1941.

Kouwenhoven, W. B. and Potter, J. H., "Thermal Resistance of Metal Contacts," J. Am. Weld. Soc., Vol. 27, Part 2, pp. 515-520, 1948.

Laming, L. C., "Thermal and Electrical Conductance of Machined Metal Contacts," University of London Ph. D. Thesis, 1959. (See also National Engineering Laboratory Heat Paper No. 182, November 1960.)

Laming, L. C., "Thermal Conductance of Machined Metal Contacts," 1961 International Heat Transfer Conference, Part 1, No. 8, pp. 65-76, Boulder, Colorado, Sept. 1961.

Lardner, T. J., "Effect of a Variable Thermal Joint Conductance," Jet Propulsion Laboratory Section Report No. 354-10, January 2, 1964.

Lardner, T. J., "Thermal Joint Conductance, Midplane Stress Distribution," Jet Propulsion Laboratory Space Programs Summary Report No. 37-19 Vol. IV, pp. 83-89, Feb. 28, 1963.

Ling, F. F., "A Quasi-Iterative Method for Computing Interface Temperature Distribution," Air Force Office of Scientific Research Report AFOSR TN58-1004, Defense Documentation Center Number AD206-147, October 1958. (See also ZEITSCHRIFT FUR ANGEWANDTE MATHEMATIK UND PHYSIK, Vol. 10, No. 5, pp. 461-474, Sept. 1959.)

Ling, F. F., PU, S. L., "Probable Interface Temperatures of Solids in Sliding Contact," Air Force Technical Documentary Report No. RTD-TDR-63-4184, DDC Number AD433587, February 1964.

Matthews, G. G., "Interface Temperature Drop Measurements Between Uranium and Magnox," C. A. Parsons and Co. Ltd. (Unpublished work).

McAdams, W. H., Heat Transmission, 2nd Ed., McGraw-Hill Book Co., New York, N. Y., 1942.

Mikesell, R. P., and Scott, R. B., "Heat Conduction Through Insulating Supports in Very Low Temperature Equipment," J. Res. N.B.S., Vol. 57, No. 6, pp. 371-378, Dec. 1956. (See also NBS Report 3507, November 18, 1954).

Miller, V. S., "Effective Method of Reducing Thermal Contact Resistance," (Russian) INZHENERNO-FIZICHESKII ZHURNAL, Vol. 6, No. 4 pp. 71-74, April 1963. English language translation by Faraday Translation, N. Y.

Miller, V. S., "Peculiarities of Control Heat Exchange Transfer in Fuel Elements of a Reactor," IZV. VYSSH. UCHEB. ZAV ENERGTIKA, pp. 67-70, No. 3, 1962. English Translation (USA) AEC-TR-5410 and NASA Technical Translation F-8849.

Miller, V. S., "Problems Concerning Contact Heat Resistance of Heat Emitting Elements," AKADEMIYA NAUK UKRAYNSKOY USSR INSTYTUT TEPLOENERGETYKY, ZBIRNY PRATS, Vol. 24, pp. 133-139, 1962. English Translation (USA) NASA Technical Translation F-8839.

Miller, V. S., "Results of Investigation of Conductive Heat Exchange Between Plane Metallic Surfaces," AKADEMIYA NAUK USSR, KIEV. INSTITUT TEPLOENERGETIKI ZBIRNY PRATS, Vol. 20, pp. 44-53, 1960. English Translation (USA) RSIC-272. Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Miller, V. S., "Determining Thermal Resistance of Conductive Heat Exchange Between Metal Ceramic Surfaces," AKADEMIYA NAUK USSR KIEV. INSTITUTE TEPLONERGETIKI ZBIRNY PRATS, Vol. 20, pp. 54-59, 1960.

Miller, V. S., "Heat Exchange Between Contacting Metal-Powder Components," DOPOVIDI AKAD. NAUK UKR. RSR, No. 1, pp. 40-43, Jan. 1961. English Translation (USA) HB-5196. Henry Brutcher Technical Translations, Altadena, California.

Mingess, M. L., "Thermal Conductance of High Temperature Metallic Honeycomb Composites," presented at the Fourth Conference on Thermal Conductivity, U. S. Naval Radiological Defense Laboratory, San Francisco, Oct. 13-16, 1964.

Moon, J. S., and Keeler, R. N., "A Theoretical Consideration of Asymmetric Heat Flow at the Interface of Two Dissimilar Metals," University of California, Lawrence Radiation Laboratory Report No. 9885, October 1961. (See also International Journal of Heat and Mass Transfer, Vol. 5, Oct. 1962, pp. 967-973.)

Neeper, D. A., Dillinger, J. R., "Thermal Resistance of Indium - Sapphire Boundaries Between 1.1-2.1°K," Phys. Rev., Vol. 135A, pp. 1028-1033, August 17, 1964.

Neider, R., "Thermal Conductance Tests on Hanford Fuel Element Bonds," Report HW-33741, 1955.

Nishiwai, J., and Hagi, S., "Thermal Conduction in Technology," (Japanese) IKAINO KENKYU (Research on Machinery), Vol. 2, No. 2, 1950-1953.

Northrup, E. F., "Some Aspects of Heat Flow," Trans. Amer. Electrochem. Soc., Vol. XXIV pp. 85-103, 1913.

Otto, L., "Studies Concerning the Warming of Electrical Machinery," (German), Mitteilungen Uber Forschungsarbeiten Auf dem Gebiete des Ingenieurwesens, Verein Deutscher Ingenieure, No. 35 and 36, Berlin 1906.

Pearson, J. A., "Interface Temperature Drop Measurements," Unpublished work of C. A. Parsons and Co., Ltd., Canada.

Pearson, J. A., "Thermal Resistance of the Joint Between a Nuclear Fuel and its Canning Material," Proc. Inst. Nucl. Engrs., December 1962.

Petri, F. J., "An Experimental Investigation of Thermal Contact Resistance in a Vacuum," ASME Paper 63-WA-156.

Podstrigach, S., "Temperature Field in a System of Solids Coupled by Means of a Thin Intermediate Layer," INZHENERNO-FIZICHESKII ZHURNAL, Vol. 6, No. 10, pp. 129-136, Oct. 1963. English Translation (USA), RSIC-148, Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Pohle, F., Lardner, T., French, F., "Temperature Distributions and Thermal Stresses in Structures with Contact Resistances," Polytechnic Institute of Brooklyn Report, PIBA 1557, Air Force Report AFOSR TN 60-504, DDC Report AD237-149.

Powell, R. W., Tye, R. P., and Jolliffe, B. W., "Heat Transfer at the Interface of Dissimilar Materials: Evidence of Thermal Comparator Experiments," Internat'l J. Heat and Mass Transf., Vol. 5, pp. 897-902, Oct. 1962.

Powell, R. W., "The Place of Heat Conduction in the Theory, Practice, and Testing of Bonds," Applied Materials Research, Vol. 1, No. 3., pp. 166-169, October 1962.

Putnaerglis, R. A., "A Review of Literature on Heat Transfer Between Metals in Contact and by Means of Liquid Metals," Report No. R. 34, Department of Mechanical Engineering, McGill University, Montreal, 1953.

Quinville, J. A., Sneyd, J. M., "Methods of Calculating Heat Conduction for Aerodynamic Heating of Supersonic Wing Structures," Appendix VII, "Temperature Distributions in Two Insulated Rods With Contact Resistance at the Plane of Contact," Northrop Aircraft Report NAI-54,DDC. No. AD 78265, June 1954.

Rapier, A. C., Jones, T. M. and McIntosh, J. E., "The Thermal Conductance of Uranium Dioxide/Stainless Steel Interfaces," Internat'l J. Heat and Mass Transf., Vol. 6, pp. 397-416, May 1963.

Robertson, A. L., Ross, A. M., Notley, M. J. F., Macewan, J. R., "Temperature Distribution in UO_2 Fuel Elements," J. Nucl. Mat., Vol. 7, No. 3, pp. 225-262, 1962; pp. 238-239 "Metal/Metal Contacts," pp. 239-242, "Metal/Ceramic Contacts."

Roess, L. C., "Theory of Spreading Conductance," Appendix A of an unpublished report of the Beacon Laboratories of Texas Company, Beacon, New York.

Rogers, G. F. C., "Heat Transfer at the Interface of Dissimilar Metals," Internat'l J. Heat and Mass Transf., Vol. 2, pp. 150-154, 1961.

Ross, A. M., Stoute, R. L., "Heat Transfer Coefficients Between UO_2 and Zircaloy 2," Atomic Energy Commission of Canada, Ltd., Report, AECL-1552, 1962.

Rosenfeld, S. J., "Analytical and Experimental Investigation of Bolted Joints," NACA TN 1458, October 1947.

Sanderson, P. D., "Heat Transfer From the Uranium Rods to the Magnox in a Gas Cooled Reactor," ASME, International Developments in Heat Transfer. Conference, Part I, No. 8, Boulder, Colorado, Sept. 1961.

Schmidt, E. H. W., and Jung, E., "Measurement of the Thermal Contact Resistance from Stainless Steel to Liquid Sodium," Modern Developments in Heat Transfer, Academic Press, N. Y., pp. 251-263, 1963.

Schaaf, S. A., "On the Superposition of a Heat Source and Contact Resistance," Quart. Appl. Math., Vol. 5, pp. 107-111, April 1947.

Seide, P., "On One-Dimensional Temperature Distribution in Two-Layered Slabs with Contact Resistances at the Plane of Contact," J. Aero/Space Sci., Vol. 25, No. 8, pp. 523-524, Aug. 1958.

Shlykov, I. U. P., and Ganin, E. A., "Thermal Resistance of a Contact," Atom. Energ., Vol. 9, No. 6, pp. 496-498, Dec. 1960. English Translation available.

Shlykov, I. U. P., Ganin, E. A., and Demkin, N. B., "Investigation of Contact Heat Exchange," (Russian with Summary in English), TEPLO-ENERGETIKA, Vol. 7, No. 6, pp. 72-76, Je'60, English Translation (USA), RSIC-117, and by United Kingdom (England) from Atomic Energy Authority Translation TRG-IS-280.

Shlykov, I. U. P., and Ganin, E. A., "Experimental Study of Contact Heat Exchange," TEPLOENERGETIKA, Vol. 8, No. 7, pp. 73-76, July 1961. English Translation (USA) RSIC-128. Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Shlykov, I. U. P., Ganin, E. A., Florinskii, "Theoretical and Experimental Study of Contact Heat Transfer," MOSKVA GOSIKOM-T PO ISPOIZOVANIIV ATOMONOI ENERGII, 60 pages 1960.

Shlykov, I. U. P., Ganin, E. E., "Heat Exchange by Contact: Heat Transfer Between Contiguous Metal Surfaces," MOSKVA GOSENERGOI ZDAT, 144 pages, 1963.

Shteinberg, V. M., "New Method for Calculating a Non-Steady State Temperature Field for a Semi-Infinite Inhomogeneous Complex of Bodies in Mutual Thermal Contact," Conference on Heat and Mass Transfer, "MINSK, Jan. 23-27, 1961.

Skipper, R. S. G., and Wooton, K. J., "Thermal Resistance Between Uranium and Can," International Conference on Peaceful Uses of Atomic Energy, Proceedings, Vol. 7, pp. 684-690, 1958.

Smith, C. F., "Apparatus for Measuring Temperature Drop Across an Interface," NASA-Marshall Technical Memorandum TMX-53091, July 17, 1964.

Sonokama, Konomo, "Contact Thermal Resistance," (Japanese) J. Jap. Soc. Mech. Engrs., Vol. 64, No. 505, pp. 240-250, 1961. English Translation (USA) RSIC-215. Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Stoyukhin, B. P., "Instantaneous Temperature at Contact Surfaces Caused by Friction," NAUCH. DOKL. VYS. SHKOLY; MASH. i. PRIB. No. 4, pp. 73-81, 1958. English Translation (USA) RSIC-142 Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Stubstad, W. R., "Thermal Contact Resistance Between Thin Plates in a Vacuum," Collins Radio Company, (Cedar Rapids, Iowa) Report 52-0756961-00181M, July, 1964. See also M. S. Thesis, State University of Iowa.

Stubstad, W. R., "Measurements of Thermal Contact Conductance in Vacuum," ASME Paper 63-WA-150.

Sud Aviation, "Thermal Conductance of Lap Joints Between AU4G1 Sheets," (French) Test Report No. C. R. 72-003-50, December 1957. English Translation (Great Britain) by G. W. Wickens, Royal Aircraft Establishment (Farnborough) Translation No. 949, June 1961. (USA, DDC, Copy No. AD-262-578.)

Sud Aviation, "Thermal Conductance of Cemented Lap Joints Between AU4G1 Sheets," (French) Test Report C. R. 72-003-51, March 1959. English Translation (Great Britain) by G. W. Wickens, Royal Aircraft Establishment (Farnborough) Translation 952, July 1961. In U. S. DDC, Cy. #262-823.

Sud Aviation, "Thermal Conductance of Steel Joints," (French) Test Report C.R. 72.013-50, March 1960, English Translation (Great Britain) by M.H.S. Brown of Royal Aircraft Establishment (Farnborough) Translation 950, July 1961. (USA, DDC, Cy. # 262820.

Swann, W. F. G., "Concerning Thermal Junction Resistances in the A. F. Jaffe Method for Measurement of Thermal Conductivity," J. Franklin Inst., Vol. 268, No. 4, pp. 294-296, Oct. 1959.

Tachibana, F., "Study of Thermal Resistances of Contact Surfaces," (Japanese) NIHON KIKAI GAKUKAI SHI, Vol. 55, No. 397, pp. 102-107, 1952. English Translation (USA) RSIC-29, Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Tampico, J., "Measurement of Contact Resistance," Dissertation at Johns Hopkins University, 1941.

Taylor, T. A., "The Thermal Conductivity of Insulating and Other Materials," Trans. ASME, Vol. 41, p. 605, 1919.

Thomas, T. R., Probert, S. D., "Variation of Thermal Conductance of Multilayered Stocks Under Load," Presented at International Thermal Conductivity Conference, National Physical Laboratory, Teddington, Middlesex, England, July 15-17, 1964.

Thomas, T. R., Probert, S. D., Warman, D., "Cryostat for Measurement of Heat Conduction Under Mechanical Loads," J. Sci. Instrum. Vol. 41, pp. 88-91, 1964.

Urakawa, K., "Graphical Solution of Contact Heat Transfer," Trans. J. Soc. Mech. Engrs. Vol. 29, No. 204, p. 1416, 1963.

USOV, A. L., "Contact Heat Transfer of a Floor Surface," (Russian), INZ. FIZ. ZHURNAL. Vol. 6, No. 11, pp. 119-122, 1963. English Translation by Faraday Translation, N. Y.

Van Dusen, M. S., "A Simple Apparatus for Comparing the Thermal Conductivity of Metals and Very Thin Specimens of Poor Conductors," J. Opt. Soc. Am. Vol. VI, p. 739, 1922.

Velissaropoulos, P. D., "Apparatus for Measuring Contact Conductance, " M.S. Thesis, M.I.T. August 1963.

Vernotte, P., "Flux Distribution of Heat Generated Between Two Media in Contact, " (French), COMPTES RENDUS 207, pp. 124-126, 1938.

Walther, J. D., "A Study of Transient Thermal Contact Conductance, " Masters Thesis Southern Methodist University, School of Engineering, Dallas, Texas, DDC No. AD 297-995.

Weills, N. D., and Ryder, E. A., "Thermal Resistance Measurements of Joints Formed Between Stationary Metal Surfaces, " Trans. ASME, Vol. 71, pp. 259-267, 1949.

Wheeler, R. G., "Thermal Conductance of Fuel Element Materials, " AEC Report No. HW-60343, 1959.

Wheeler, R. G., "Thermal Contact Conductance, " AEC Report No. HW-53598, November 1957.

Williams, A., "Comment on Rogers' Paper' Heat Transfer at the Interface of Dissimilar Metals, " Int. J. Heat Mass Transf. Vol. 3, p. 159, 1961.

Williams, A., "Heat Transfer at the Interface of Dissimilar Metals, A Further Consideration, " University of Manchester (England) Report ARC.23, 498 STRUT. 2409, February 1962.

Wong, H. Y., "Thermal Conductance of Metallic Contacts - A Survey, " presented at the International Conference on Thermal Conductivity, National Physical Laboratory, Teddington, Middlesex, England, July 15-17, 1964.

Wright Patterson Air Force Base Report, "Thermo-Mechanical Analysis of Structural Joint Study, " Report WADD TR61-5, January 1962.

Yamauchi, K., "Graphical Solution of Contact Heat Conduction, "(Japanese), Transactions of Japan Society of Mechanical Engineers, Vol. 29, No. 201, pp. 1001-1004, 1963.

Zavaritskii, N. V., "Thermal Resistance of Metal Surfaces in Contact in Helium Atmospheres," *Journal of Technical Physics, USSR*, Vol. 21, pp. 453-457, 1951.

II. CONTACT SURFACE PARAMETER STUDIES

Batho, C., "The Partition of the Load in Riveted Joints, J. Franklin Inst. Vol. 182, No. 5, 1916.

Bowden, F. P., Tabor, D., "The Area of Contact Between Stationary and Moving Surfaces," Proc. Roy. Soc. Lond. A. 169, 1939.

Carroll, T. W., "Statistical Calculation of Geometric Parameters for Semi-Smooth Contiguous Surfaces," M. S. Thesis, M.I.T., January 1962.

Cunnington, J. W., Spretnak, J. W., "A Study of the Effect of Applied Pressure on Surface Contact Area," *J.M.S.* Vol. 4, 1962.

D'YACHENKO, P. E., TOLKACHEVA, N. N., ANDREEV, G. A., KARPOVA, T. M., "The Actual Contact Area Between Touching Surfaces," (Russian), Institute of Mechanical Engineering, Academy of Science Press, Moscow, 1963, 68 pages. English Translation by Consultants Bureau, N. Y. 1964.

Dyson, J., Hirst, W., "The True Contact Between Solids," Proceedings of the Physical Society, Section B., Vol. 67, pp. 390-312, 1954.

Flamming, D. C., "The Use and Comparison of Autoradiographical and Statistical Methods for Determining the Number of Contacts Between Two Surfaces Pressed Together," B.S. Thesis, M.I.T., June 1963.

Hertz, Heinrich, "Study of the Contact of Elastic Solid Bodies," (German), *Journal For die Reine and Angewandte Mathematik*, Vol. 29, pp. 156-171, 1882, English Translation (USA) by EGON BENESI, Translation No. SLA 57-01164.

IWAKI, A., MORI, M., "Distribution of Surface Roughness When Two Surfaces are Pressed Together," Bull. Jap. Soc. Mech. Engr. Vol. 1, pp. 229-337, 1958.

KASZUBINEKI, L. J., "Determination of the Number of Contacts Between Two Surfaces Pressed Together," M. S. Thesis, M. I. T., August 1962.

Ling, F. F., "An Asperity Distribution of Metallic Surfaces," J. Appl. Phys. Vol. 24, No. 8, August 1958.

Ling F. F., Lucek, R. C., "On Model Studies of Metallic Surface Asperities," Air Force Office of Special Research Report TN58-1134, (USA DDC Cy. # AD 208-083, December 1958.)

Mueller-Hillebrand, D., "Surface Contacts Under High Load Forces," Wiss. Veroeff. Siemenswerke, Vol. 20, pp. 85-103, 1941.

Shetsova, E. M., "Determination of Actual Contact Areas of Surfaces by Means of Transparent Models," (Russian) AKADEMIA NAUK SSSR, INSTITUT MASAINOVEDENIA, SBORNIK IZNOS V. MASHINAKH, Vol. 7, pp. 12-33, 1953, English Translation (USA) RSIC-192, Redstone Scientific Information Center, Redstone Arsenal, Alabama.

Tarasov, L. P., "Relation of Surface Roughness Readings to Actual Surface Profile," Trans. ASME, Vol. 67, No. 3, April 1945.

Tate, M. B., Rosenfeld, S. J., "Preliminary Investigation of the Loads Carried by Individual Bolts in Bolted Joints, NACA TN 1051, May 1946.

Testerman, M. K., "Method of Determining Surface Roughness," WADC Technical Report 58-230, DDC Cy. # AD 155-828.

Voigt, F., "The Load Distribution in Bolted or Riveted Joints in Light Alloy Structures," NACA TN 1135, April 1947.


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